

5-5-1977

MTF and Adjacency Effects of Vesicular Film

Timothy Sewell

Paul Willig

Follow this and additional works at: <http://scholarworks.rit.edu/theses>

Recommended Citation

Sewell, Timothy and Willig, Paul, "MTF and Adjacency Effects of Vesicular Film" (1977). Thesis. Rochester Institute of Technology. Accessed from

This Thesis is brought to you for free and open access by the Thesis/Dissertation Collections at RIT Scholar Works. It has been accepted for inclusion in Theses by an authorized administrator of RIT Scholar Works. For more information, please contact ritscholarworks@rit.edu.

MTF AND ADJACENCY EFFECTS OF VESICULAR FILM

by

Timothy J. Sewell
&
Paul J. Willig

Thesis Advisor: Dr. Ed Granger
Date: May 5, 1977

Ed Granger

Submitted to: Dr. G.W. Schumann, Graduate Coordinator
Department of Photographic Science and Instrumentation
Rochester Institute of Technology, Rochester, New York

9924173

ABSTRACT

The Modulation Transfer Function and adjacency effects are important measurements of a photographic material. For vesicular film it is of interest to investigate the MTF and adjacency effects with relation to the three variable parameters, development temperature, exposure and development time. This investigation clearly shows that adjacency effects do occur in vesicular film, and that exposure and development temperature are important factors in determining the film MTF.

TABLE OF CONTENTS

ABSTRACT	page 1.
INTRODUCTION	pages 1 - 6
EXPERIMENTAL	pages 7 - 14
RESULTS	pages 15 - 22
DISCUSSION	pages 23 - 34
CONCLUSION	page 35
ACKNOWLEDGMENTS	page 36
APPENDIX 1.	pages 37 - 38
REFERENCES	pages 39 - 40

INTRODUCTION

Vesicular photographic materials are based upon the principle of light scattering, rather than light absorbing as are conventional silver halide materials. The two systems are compared in Figure 1, where in A the incident light is absorbed by the silver grains and in B the light scattering vesicles reflect and refract the light.

Vesicular film consists of a thermoplastic resin which is coated onto a transparent Mylar backing. Within the thermoplastic resin, which is coated to a thickness between 0.00025 inches and 0.00055 inches, there is uniformly dispersed a diazonium salt. This compound is sensitive to ultra violet radiation, and upon exposure decomposes to release nitrogen gas (Figure 2.). Upon the application of heat, the nitrogen gas assembles and expands to form microscopic vesicles. These vesicles, since they are of a different index of refraction than the surrounding medium, scatter light which is incident upon them and thus form the image. The light scattering elements can vary in diameter from 0.5 microns to 2.0 microns. Due to the nature of these materials, the Mylar backing and the thermoplastic resin, the light scattering elements are highly resistant to environmental changes and thus form a very stable image.

Exposure to U.V. Radiation

Vesicular materials are sensitive to radiation in the ultra violet portion of the spectrum. Their maximum sensitivity is at 385 nm and the spectral response of these materials, as shown in Figure 3, extends from below 335 nm to above 415 nm. The amount of radiation, at the

wavelength corresponding to peak sensitivity, to produce maximum density is generally about 200 milliwatt seconds/cm². Vesicular films are not photographically sensitive to moderate levels of visible light for short periods of time.

Exposure times are determined by the time required to obtain 200 milliwatt seconds/cm² of actinic energy on the film. Considering the fact that the latent image produced is gaseous and that the image forming gas diffuses from the material, the reciprocity law is valid for exposure times over an approximate range of 1 second to 60 seconds. Exposure times over 60 seconds are useful but the density produced is no longer proportional to the exposure time, and exposure times above 3 minutes are not advisable.

Energy in the spectral region to which vesicular film is sensitive can be supplied by mercury vapor lamps. The temperature of the film during exposure should not exceed 110°F. Above this, a premature development will result, and a higher rate of diffusion of the image forming gas so that both the density and resolution obtained will be reduced.

Development

Vesicular films are developed by heat. The heat necessary for development may be conducted into the film by a heated roller, a platen, or a liquid medium such as glycerin. Satisfactory development may be obtained at temperatures ranging from 180°F to over 300°F, and at times ranging from milliseconds to 5 seconds. The only basic requirement is that 0.5 cal/cm² be transferred to the film. However, a development time of more than 2 seconds would require a development temperature below

240°F which will produce an unstable image.

Since the latent image in vesicular film is unstable, and will decay at a finite rate depending upon the temperature, development should always follow as soon as possible after exposure. Noticable image deterioration may occur if more than one minute elapses between exposure and development.

As with most photographic processes, there is a stabilizing technique which can be used for vesicular film. After exposure and development, the film still contains undecomposed diazonium salt. If the film is given an overall exposure, following the initial exposure and development, any residual diazonium salt will be decomposed. The film must then be protected from temperatures above 110°F for several hours so that the nitrogen gas formed can completely diffuse from the material. The duration of the clearing exposure should be about four times the exposure required to produce maximum density.

Photographic Characteristics

Due to the unique characteristics of vesicular films many of the terms that apply to conventional silver photography are no longer relevant. When light is incident on an exposed and developed sample of vesicular film, part of the light is reflected, part is absorbed and part is transmitted, with the transmitted and reflected light being scattered. The receiver or collector of a densitometer may collect all or only a portion of the incident light relative to the film sample. Vesicular film is most widely used in projection systems where the incident light is parallel. The measured density, in such a system, consists of the transmitted light which enters a given aperture, at a

specified distance from the film plane, and is collected. Therefore the measured density is dependent upon the relative aperture of the projection system (Figure 4). As the aperture decreases in area the measured density and gamma of the material increases.

Development time and temperature also have a marked effect on the vesicular characteristic curve. Figure 5 shows the $D - \log H$ curves for projection densities when the film is underdeveloped, overdeveloped and properly developed. Underdevelopment causes an increase in the toe portion of the curve and the maximum density is not fully developed. Overdevelopment causes image decomposition in the higher density areas but at the middle density range this curve is comparable to the properly developed curve.

Resolution values in vesicular film can be as high as 1000 cycles/mm. Previous work by Norcross has shown that development time and temperature greatly influence the resolving power of vesicular film. As development temperature decreases resolving power increases. Development time does not have as large of an effect on the resolving power.

There are still many areas to be investigated in order to fully understand the vesicular image. At the present time little or no published data is available. Therefore it is of interest to determine the MTF (Modulation Transfer Function) and the adjacency effects, of these materials, and what relationship exists, if any, between these effects and development time, development temperature and exposure.

FIGURE 1.

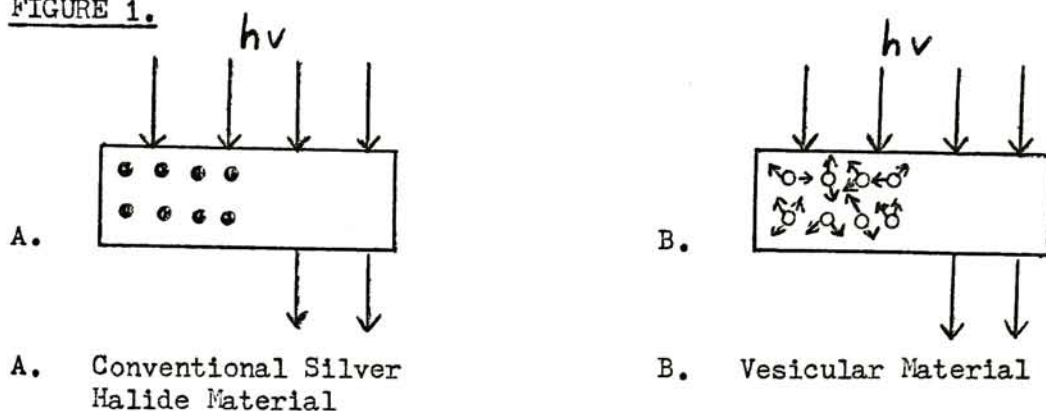


FIGURE 2.

Decomposition of diazonium salt

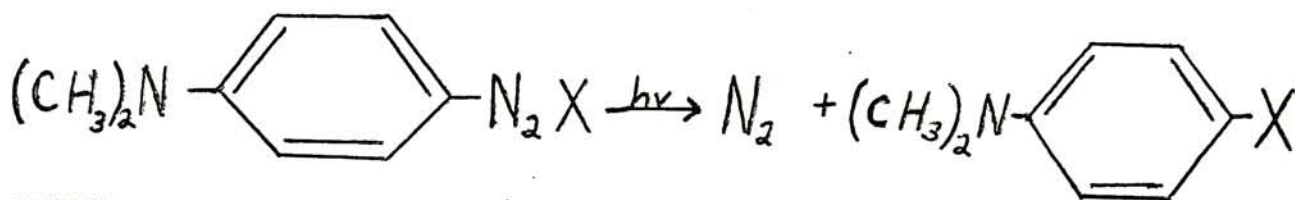


FIGURE 3.

Spectral Photosensitivity

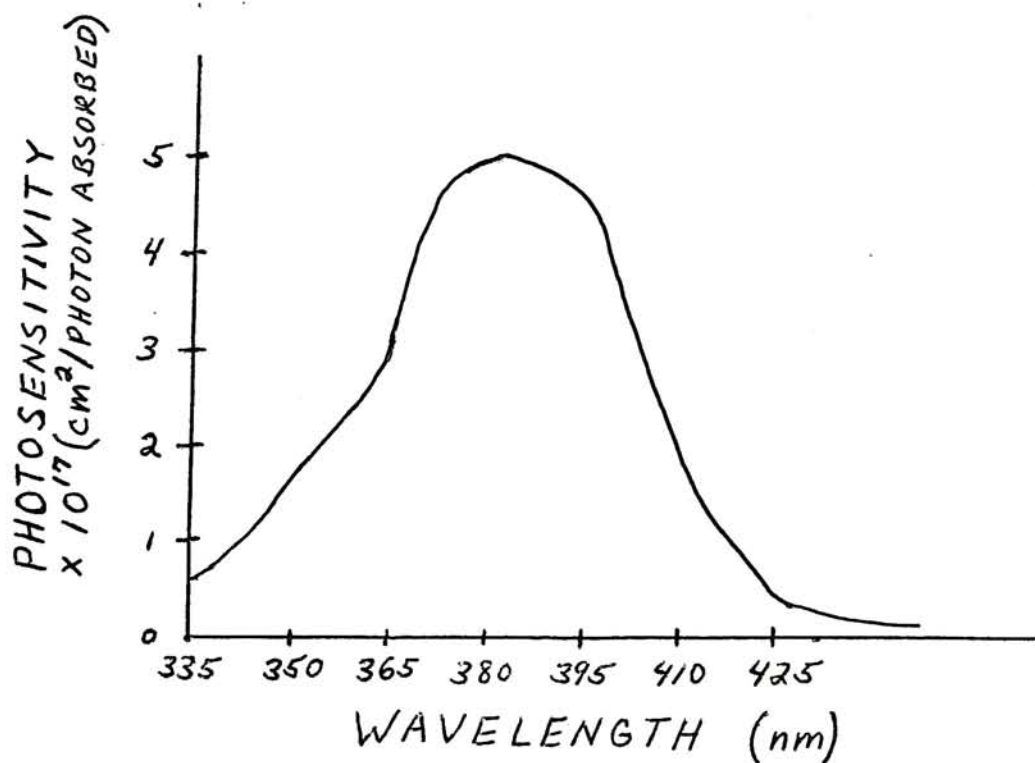


FIGURE 4.

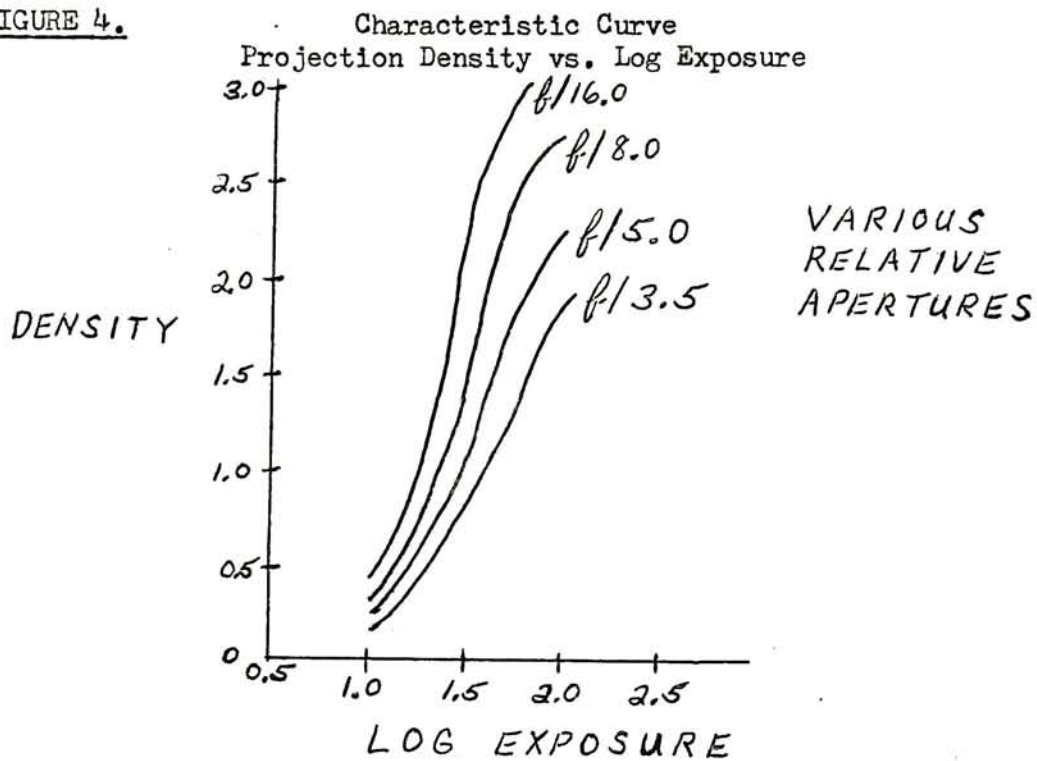
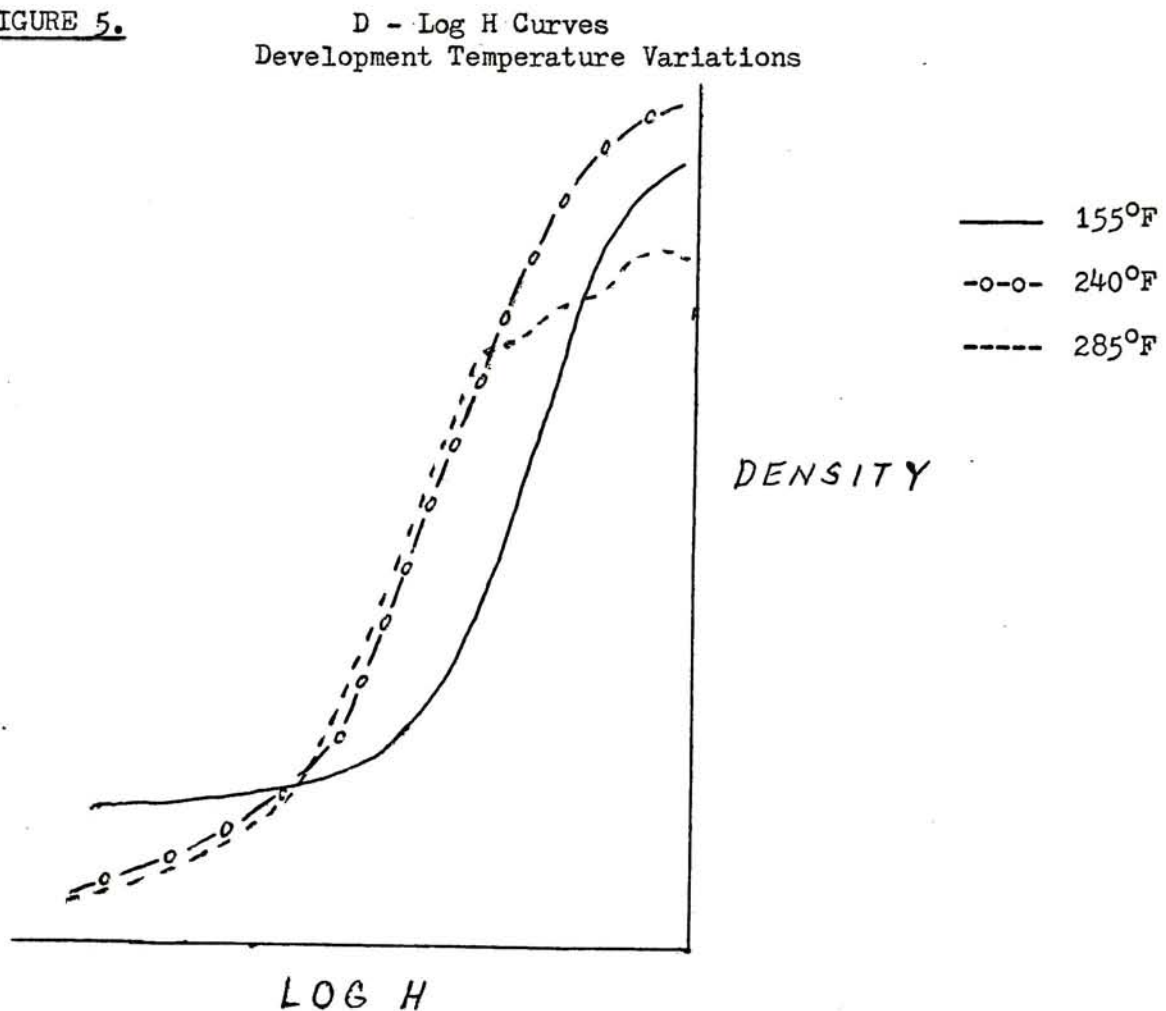


FIGURE 5.



EXPERIMENTAL

To investigate the adjacency effects and MTF of this vesicular film a basic experimental procedure was followed. This involved exposing an edge onto the vesicular material, followed by development of the film to produce an image of the edge. This image was then scanned with a microdensitometer to obtain edge traces. From these traces the MTF curves and adjacency effects can be calculated. The exact method of analysis of the edge traces will be discussed in the next section of this report.

Investigation of the adjacency effects and MTF curves for vesicular film, with relation to development temperature, development time and exposure, involves a three factor experiment. The experimental design used was a central composite design for three factors. This design allows for the exploration of three variable parameters while keeping the number of treatments low. As seen in Figure 6 the total number of treatments is 20, and there are 5 levels for each of the 3 factors. With the exception of the central point, which is replicated 6 times in order to get an estimate of experimental error, the various treatments are placed on the surface of a sphere and they are all an equal distance from the central point. By setting the ranges of the 3 factors and following the treatment combinations this sphere and central point are being investigated. Any relationship existing between the measured effect and the 3 variable parameters, for the set ranges, can be determined. This design has the advantage of only 20 treatments,

while in a 3^5 experiment 243 treatment combinations would be necessary. Therefore there is a great saving on cost and time by using a central composite design. The ranges of the 3 variable parameters were set as follows; development temperature from 180°F to 300°F , development time from 1 second to 5 seconds, and exposure time from 1 second to 60 seconds. In Figure 6 a complete list of the treatment combinations, for these ranges, is given.

The vesicular material used in this study was Xidex Super-X film. This vesicular film is in a 16mm format and is presently used in the microfilm industry.

Exposure

Xidex Super-X film, as with all vesicular materials, is sensitive to ultra violet radiation. Therefore the apparatus used for exposure was a Colight Model K10 unit, which basically consists of a mercury vapor lamp and a vacuum platen for holding the film sample. The lamp was a General Electric 400 watt mercury vapor lamp, number H-400A33-1 T/16, which emits a strong band in the ultra violet portion of the spectrum at 380 nm. The Colight Model K10 unit was modified by building a sliding shutter onto the platen, this was done in order to obtain accurate exposure times.

It was necessary to measure the illuminance of the lamp at the platen so that accurate exposure values for the film could be determined. These exposure values, expressed as log exposure, were needed so that characteristic curves could be determined for the vesicular film. By using a Hewlett-Packard Model 8330A Radiant Flux meter and a Kodak 18A

Wratten filter, which transmits between 320 nm and 400 nm, illuminance measurements were made. The illuminance at the platen, where the film sample is located, was calculated to be 2.76 mW/cm^2 .

The edge used in exposing all film samples was a NBS (National Bureau of Standards) multiple density edge. This edge consists of ten various density patches and five different edges, which are on a 35 mm format film. For the exposures of the vesicular samples the edge was placed between the cover glass of the platen and the film sample to be exposed. This NBS edge was number VCE-010 and had densities ranging from 2.91 to 0.25. Since this edge is comprised of various density patches it was also used to obtain characteristic curves for the vesicular samples.

After some preliminary exposures of the film sample a difficulty arose, in that Newton's rings could be seen between the glass-edge and edge-film interfaces. These rings were caused by small spaces between the three different materials. It was found that the vacuum itself was not able to maintain the close contact, between the three different materials, that would be necessary to eliminate the Newton's rings. With the rings present and the film sample exposed and developed the patterns of the rings could be seen on the final image. Therefore spectroscopic grade m-Xylene was used between all the interfaces. This eliminated the Newton's rings and maintained close contact between the three materials, and because the m-Xylene was of spectroscopic grade it did not cut out any portion of the ultra violet radiation.

Once this problem was solved all film samples were exposed following the composite design. The time between exposure and development was

maintained at less than one minute to guarantee a minimum amount of diffusion of the nitrogen in the exposed film sample.

Development

As previously stated vesicular materials are developed by the application of heat, and there are many different processes which can be used for this transfer of heat. The first attempt at a reliable development method involved the use of glycerin as a heat transferring medium. At first there seemed to be many advantages to the use of glycerin. It is water soluble, yields a uniform temperature, does not boil over the range of development temperatures used and glycerin will not attack the vesicular material. The method of development, with the glycerin, was to heat the glycerin in a copper trough and then transport the exposed film sample through the glycerin by attaching it to a reel that was rotated by a variable speed motor. Employing a variable speed motor allowed the freedom of arriving at the various development times. Preliminary results showed that there were also many problems encountered while using the above method. Once the variable speed motor was set to yield the correct development time it had to be stopped in order to attach the film sample to the reel. This stop-start of the motor produced development times which were inaccurate. Also when the film was transported through the glycerin there was a problem of carry over. Since some of the heated glycerin remained on the film the developed image was not uniform. Therefore a new development process had to be set up.

An alternative method involved the use of a Kalvar 160 processor. This processor consists of a heated platen and a roller system to

transport the film over the platen. The temperature of the platen could be varied by means of a thermostat adjustment, and accurate temperature readings ($\pm 1/2^{\circ}\text{F}$) were obtained by attaching a copper constantan thermocouple to the platen and using a Leeds & Northop Volt Potentiometer. In order to achieve the range of development times necessary the transport motor of the processor was removed and replaced with a Bodine type NSH-12R variable speed motor. Varying the speed of this motor made it possible to vary the development times. Since the motor could be kept running constantly, after being set at the correct speed, there was no stop-start problem, which plagued the previous method. Very satisfactory results were obtained using this new method of development. Following the composite design all exposed film samples were developed using this method.

Following development it was necessary to fix the film sample to insure that the final image would be stable and not effected by any environmental changes. Fixation consisted of giving the developed film sample an overall ultra violet exposure for two minutes and then allowing it to stand for several hours.

Evaluation

Once all the film samples had been exposed and developed they were evaluated using a microdensitometer. The final vesicular images consisted of ten different density patches and five different edges.

As previously stated, scanning of the vesicular images would be accomplished by setting up the microdensitometer so that it duplicates a $f/4.5$ projection system. Since vesicular film is designed for use in

a projection system this method of scanning will give the most worthwhile measurement of the vesicular image.

The microdensitometer used for all the scanning was an Ansco Model IV. The influx and efflux objectives chosen were 0.10 numerical aperture, this yields an f/number of $f/5.0$. Also the illuminating slit was opened to the widest position and an effective aperture of $2.5\mu\text{m} \times 300\mu\text{m}$ was employed in scanning the samples.

Scans of the ten various density patches for each sample were made. Characteristic curves of the vesicular film could now be drawn using the information from these scans. Since there were five different edges on each sample the characteristic curves served the purpose of choosing an edge for each sample that fell on the linear portion of the characteristic curve. Once this was done one edge for each sample was scanned, and five traces were made for each edge in order to get an estimate of error. Also the NBS edge was scanned using the microdensitometer in the same manner as for the vesicular samples. By doing this the MTF of the microdensitometer could be calculated. This would be of importance in the following analysis of data.

From the edge traces MTF curves and adjacency effects can be calculated. In the next section of this report the exact method of analysis, of the edge traces, to yield the MTF curves and adjacency effects will be discussed.

FIGURE 6.

Central Composite Design

Development Temperature	-1.68	-1	0	1	1.68
	180	204	240	276	300

Development Time	-1.68	-1	0	1	1.68
	1	1.8	3	4.2	5

Exposure Time	-1.68	-1	0	1	1.68
	1	12	30	48	60

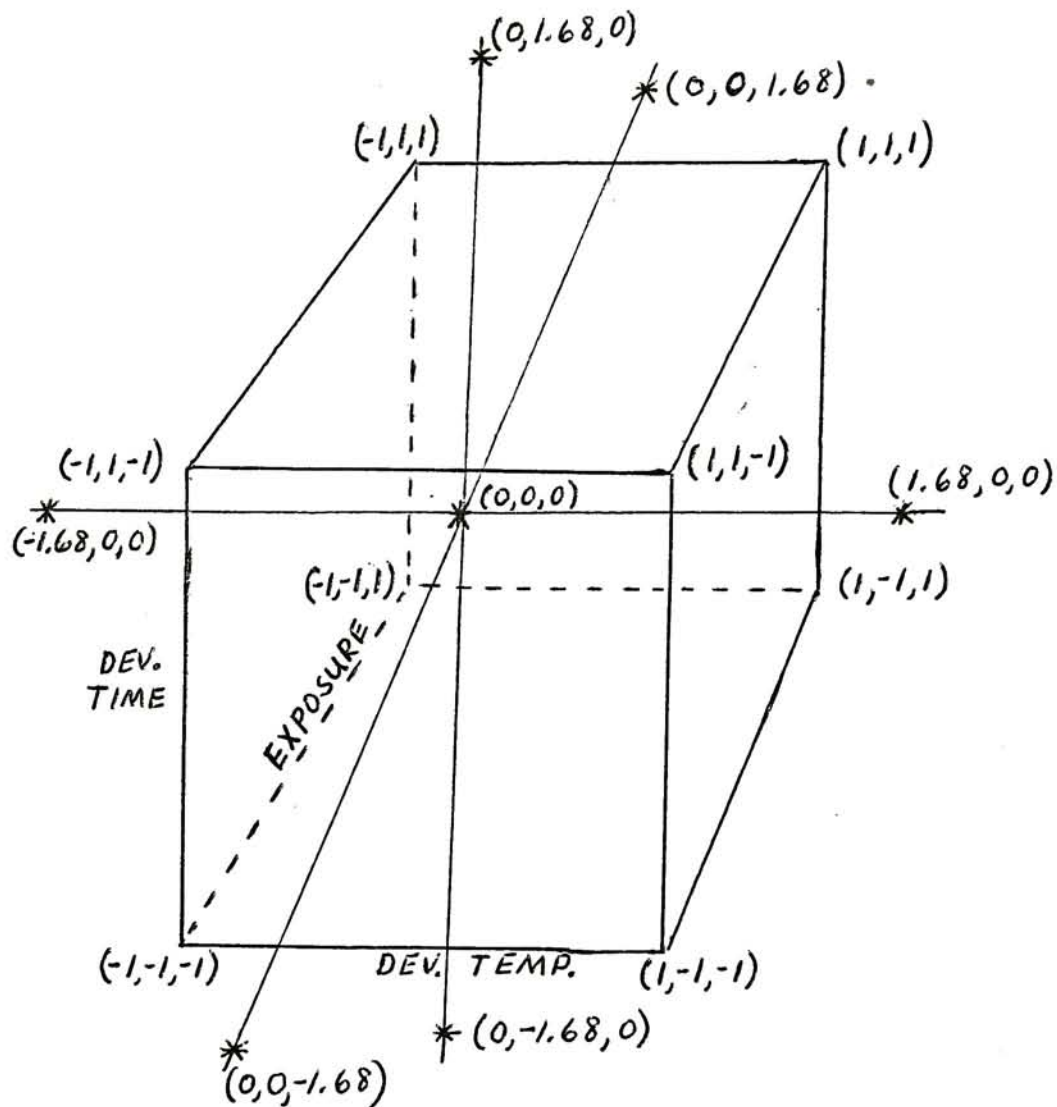


FIGURE 6 (cont.)

Central Composite Design

Treatment Combinations in Randomized Order

<u>Sample Number</u>	<u>Development Temperature</u>	<u>Development Time</u>	<u>Exposure Time</u>
1.	0	0	1.68
2.	0	0	0
3.	1	-1	1
4.	1	1	-1
5.	0	0	0
6.	-1	-1	1
7.	0	0	-1.68
8.	1	-1	-1
9.	-1	1	1
10.	-1	1	-1
11.	0	0	0
12.	0	1.68	0
13.	-1.68	0	0
14.	0	0	0
15.	0	-1.68	0
16.	1	1	1
17.	1.68	0	0
18.	0	0	0
19.	-1	-1	-1
20.	0	0	0

Actual Treatment Combinations in Randomized Order

(Sample number corresponds to sample number in above table)

<u>Sample Number</u>	<u>Development Temperature(F)</u>	<u>Development Time(sec.)</u>	<u>Exposure Time(sec.)</u>
1.	240	3	60
2.	240	3	30
3.	276	1.8	48
4.	276	4.2	12
5.	240	3	30
6.	204	1.8	48
7.	240	3	1
8.	276	1.8	12
9.	204	4.2	48
10.	204	4.2	12
11.	240	3	30
12.	240	5	30
13.	180	3	30
14.	240	3	30
15.	240	1	30
16.	276	4.2	48
17.	300	3	30
18.	240	3	30
19.	204	1.8	12
20.	240	3	30

RESULTS

Upon completion of the edge traces the MTF curves for the vesicular samples could be calculated. From the MTF curves any adjacency effects that occur can be seen.

The exact method of determining the MTF from an edge trace is based on previous work by Straw. The general theory that this method is based upon is shown by the equations in Figure 7. As shown in Eq. (1) $e(f)$ is set equal to the Fourier transform of the edge function $E(x)$. Therefore $E(x)$ is equal to the inverse Fourier transform of $e(f)$, and by taking the derivative of this function, Eqs.(2&3), the line spread function $L(x)$ is obtained. Since $L(x)$ is equal to the inverse Fourier transform of the Optical Transfer Function, Eq.(4), the OTF can now be calculated, Eqs.(5&6). In order to obtain the MTF it is necessary to take the modulus of the OTF.

A computer program was written to accomplish this procedure and to produce the MTF values (Appendix 1.). By inputting data from the five edge traces, for each sample, the output would consist of the MTF values for each trace, the real and imaginary parts of the MTF values and an average MTF curve for each sample. The MTF curves obtained were of the system, which included the vesicular film and the microdensitometer.

Figure 8 shows a typical edge trace and how data was taken from this trace to be inputted into the computer. The computer program previously mentioned operates in the transmittance domain, but the data input is in the form of density. For each edge trace it was necessary to locate a center point and then take an equal number of samples on each side of the center point, at an equal interval of 1.25 μm . To obtain

the center point D_{max} and D_{min} were changed to transmittance and then these two values were averaged. This yielded an average transmittance value for the edge trace, which could now be converted back into density to produce the value of the center point.

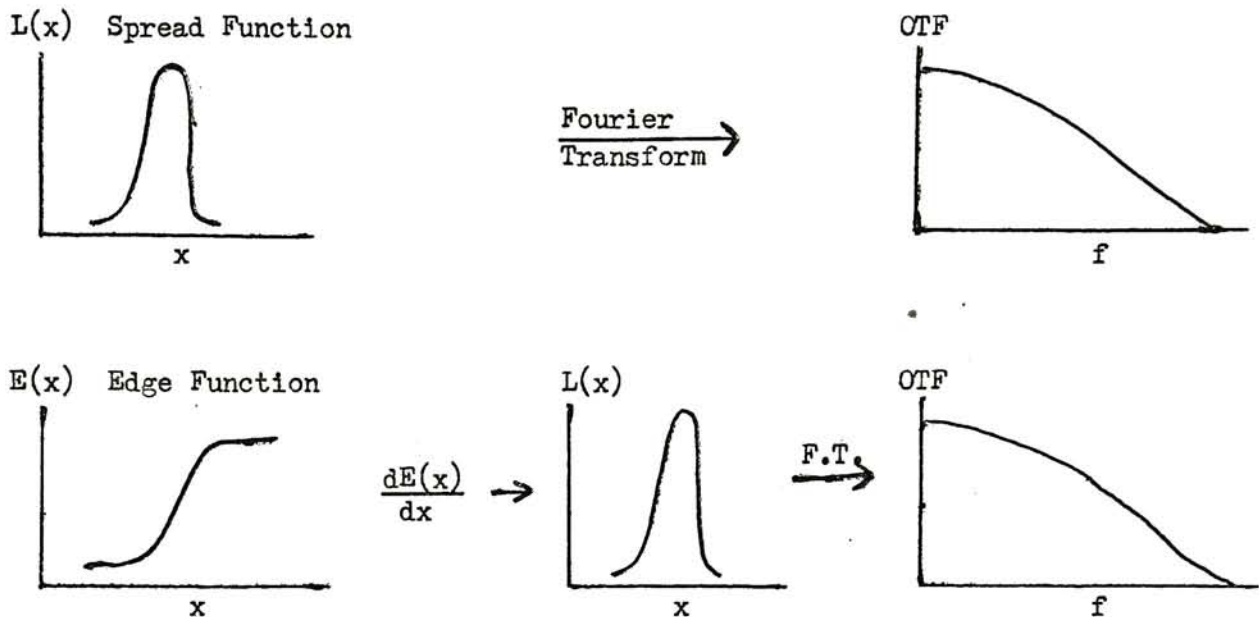
In the same manner the edge traces for the NBS edge were evaluated. Since the NBS edge was considered a "perfect" edge the MTF curve produced was for the microdensitometer. In order to find out exactly how good a measurement this actually was a theoretical MTF curve for the microdensitometer was calculated. To calculate the theoretical MTF the MTF of a diffraction limited lens, the sampling plan of the edge traces and the effective aperture used in the scanning were taken into account. In Figure 9, the theoretical and calculated MTF curves for the microdensitometer are compared. There is a difference between the two curves, however this could be attributed to such factors as flare and focus which were not taken into account in calculating the theoretical curve.

A scatter plot, for the five edge traces of the NBS edge, was drawn (Figure 10.). The plot consisted of the real and imaginary parts of the MTF values, for a certain frequency. The diameter of the scatter plots is 0.146 for the 50c/mm case and 0.183 for the 70c/mm case. This plot shows that the variability between the five edge traces is very low. Therefore the calculated MTF curve in Figure 9. is a worthwhile measurement of the microdensitometer.

In a photographic system MTF curves of the elements may be cascaded in order to calculate a system MTF curve. Therefore if the system MTF

curve is known it may be divided by the MTF of one of the elements to yield the MTF value of the second element. This procedure was followed in determining the MTF curves for the vesicular film. Since the system MTF curve was previously calculated using the computer program, and the MTF of the microdensitometer was found using the NBS edge, the system MTF was divided by the microdensitometer MTF to yield the film MTF. Figure 11. shows the average system and film MTF curves for the central point in the composite design. From this graph it is obvious that the film MTF curve must be used in order to uncover effects, such as adjacency effects, in the film.

FIGURE 7.



$$(1) \quad e(f) = \int_{-\infty}^{\infty} E(x) e^{-i2\pi f x} dx$$

$$(2) \quad L(x) = \frac{dE(x)}{dx} = \frac{d}{dx} \left(\int_{-\infty}^{\infty} e(f) e^{i2\pi f x} df \right)$$

$$(3) \quad L(x) = \int_{-\infty}^{\infty} i2\pi f e(f) e^{i2\pi f x} df$$

$$(4) \quad L(x) = \int_{-\infty}^{\infty} \text{OTF}(f) e^{i2\pi f x} df = \int_{-\infty}^{\infty} i2\pi f e(f) e^{i2\pi f x} df$$

$$(5) \quad \text{OTF}(f) = i2\pi f e(f)$$

$$(6) \quad \text{OTF}(f) = i2\pi f \int_{-\infty}^{\infty} E(x) e^{-i2\pi f x} dx$$

$$(7) \quad \text{MTF} = |\text{OTF}|$$

FIGURE 8. TYPICAL EDGE TRACE

Samples taken every 1.25 μ m.

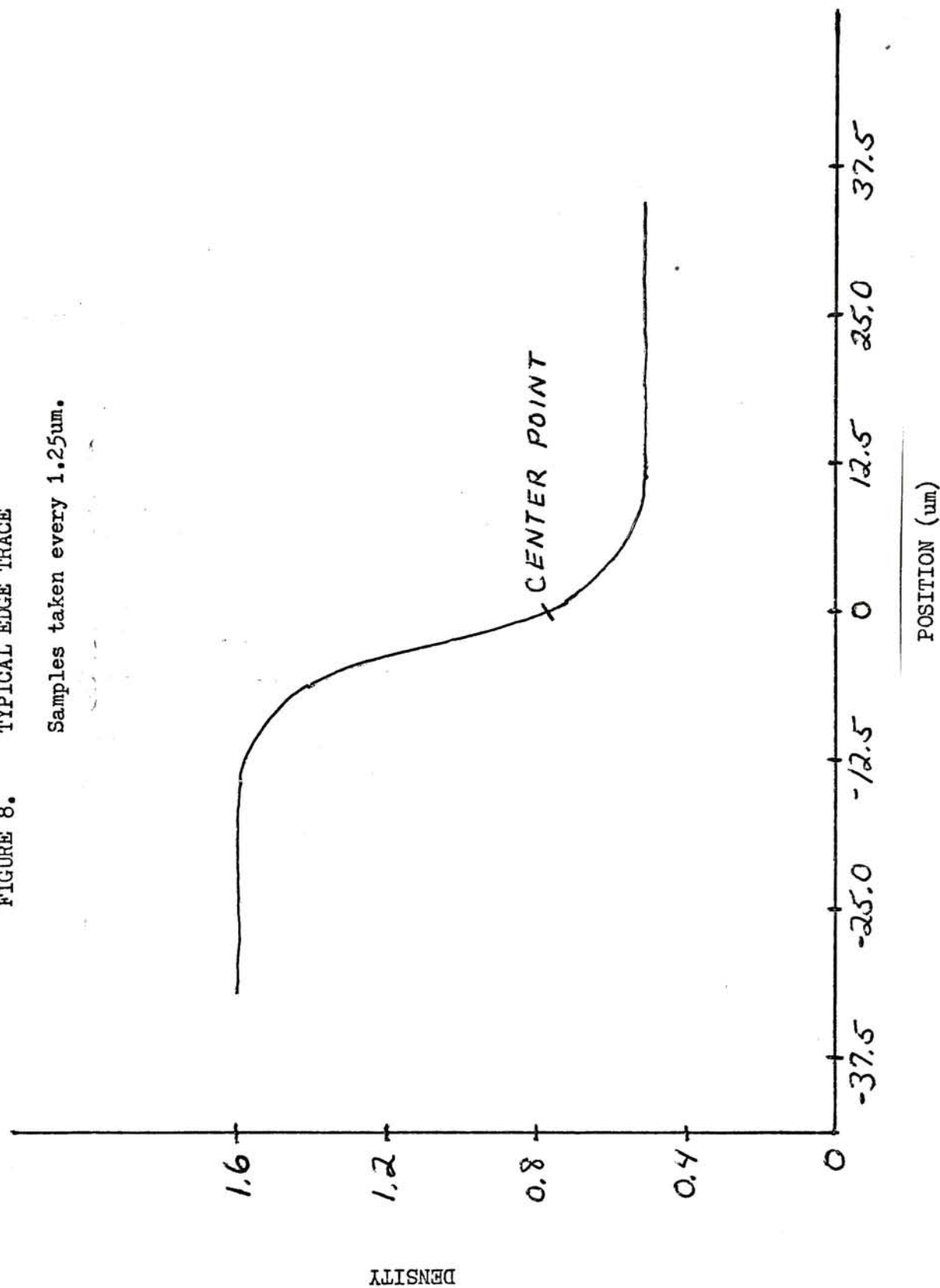


FIGURE 9. - - - THEORETICAL MTF of MICRODENSITOMETER

— CALCULATED MTF of MICRODENSITOMETER

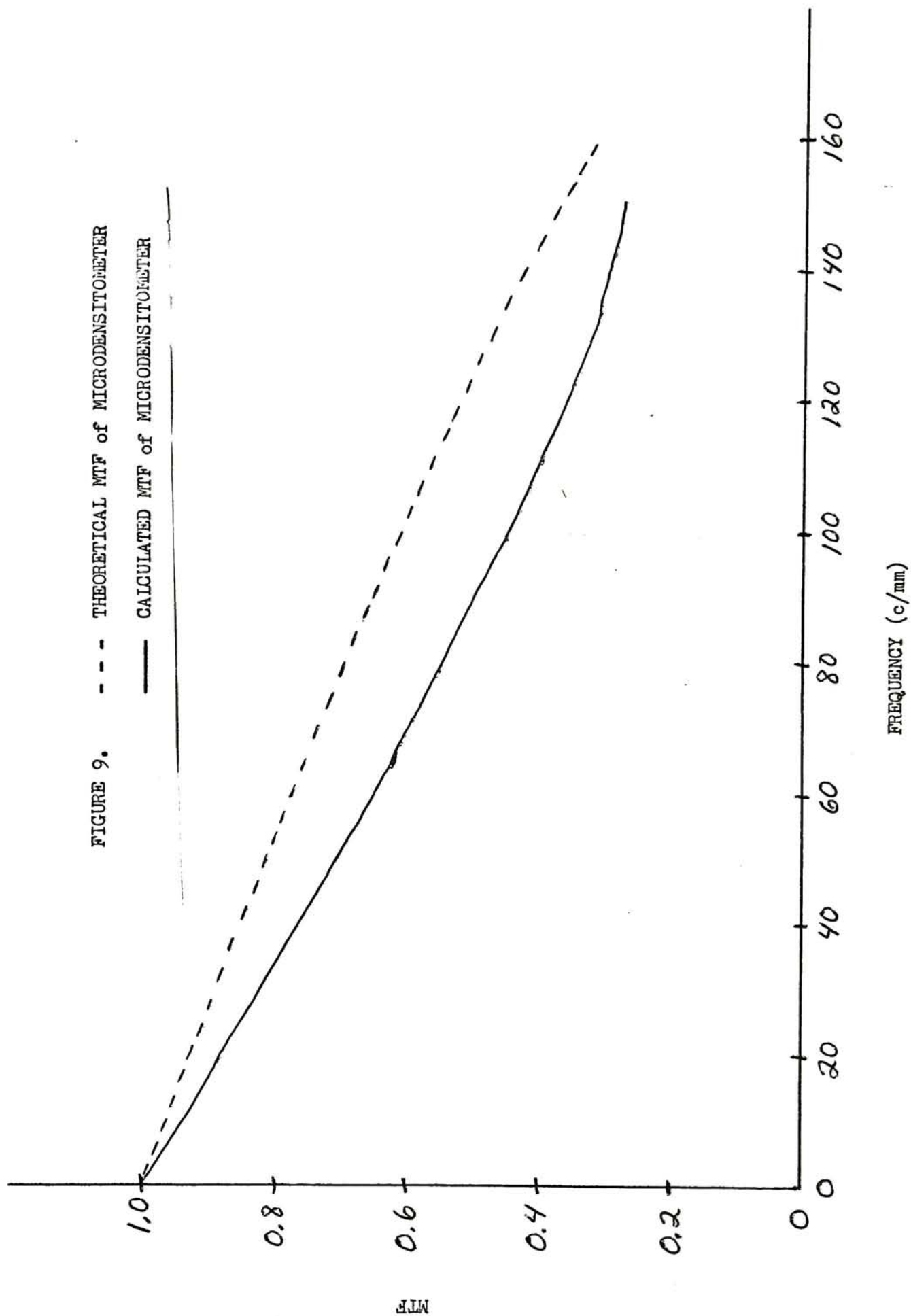


FIGURE 10. SCATTER PLOT FOR NBS EDGE

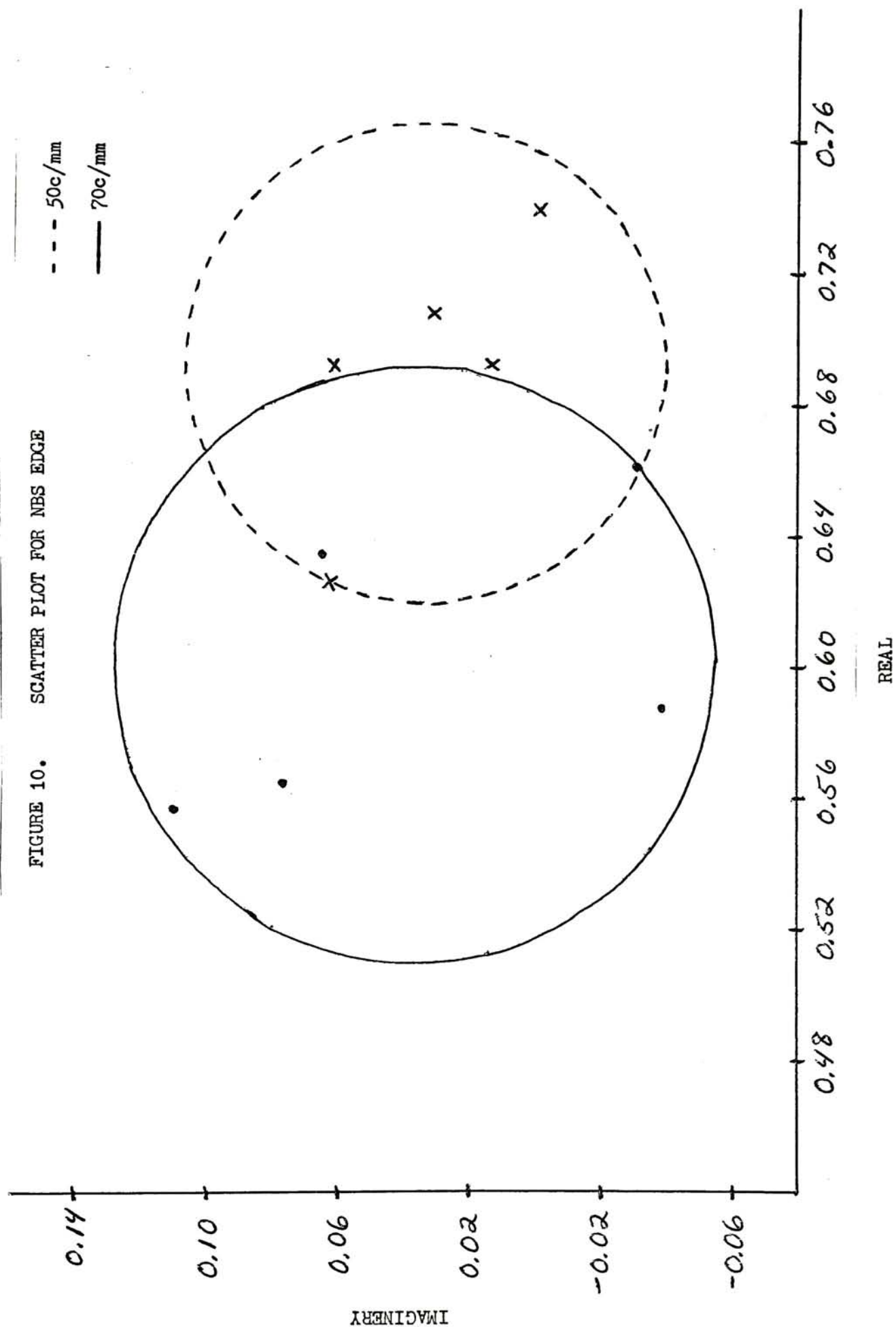
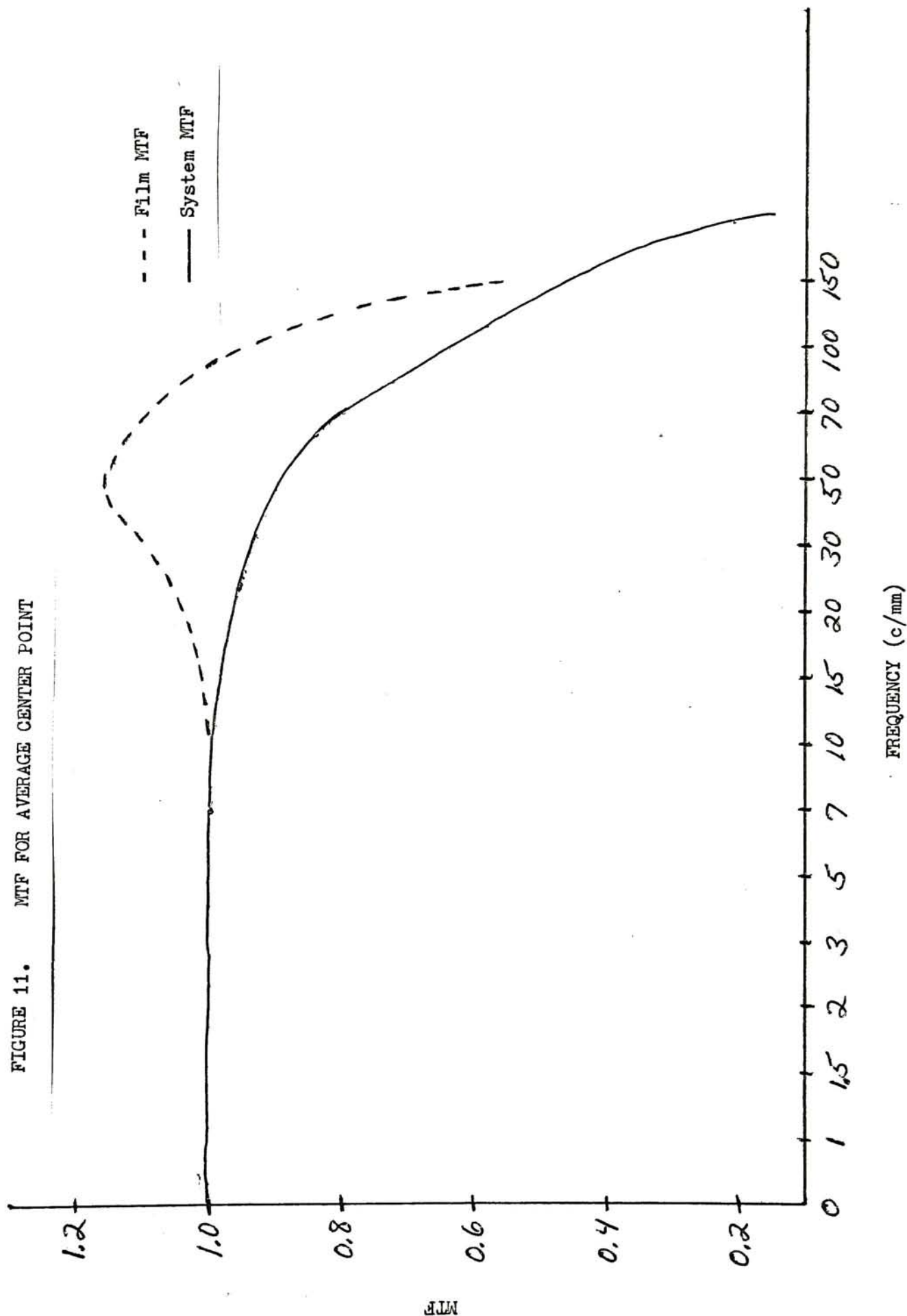


FIGURE 11. MTF FOR AVERAGE CENTER POINT



DISCUSSION

A very useful property of a film MTF curve is that if an adjacency effect exists in the film it will be apparent by looking at this curve. This is due to the fact that an adjacency effect causes the MTF of the film to be greater than one.

The MTF curves drawn for the vesicular samples do exhibit adjacency effects for certain treatment combinations. These treatments are in the region around the central point of the composite design. The central point has a development temperature of 240°F, an exposure of 30 seconds and a development time of 3 seconds. Adjacency effects occurred for all six replicates of the central point, with the greatest adjacency effect occurring in sample #2 (Figure 12.). As in all the cases where adjacency effects are seen, they are present between 10c/mm and 125c/mm, with the maximum MTF value at 50c/mm or 70c/mm.

A useful insight, as to the choice of a regression model, was obtained by exploring the axis of each variable parameter. In these plots (Figures 13, 14 & 15) MTF values, for a certain frequency, were graphed as a function of one of the three variable parameters, with the other two remaining constant. The graphs indicate a quadratic relationship and therefore a regression model was chosen to fit this relationship.

The regression model used was a multiple linear stepwise regression. Using a computer program the three variable parameters, with their squares and cross products, were fit into a regression model as a function of MTF.

From the results obtained five factors stood out as significant in the regression model, these factors being exposure, exposure squared, development temperature, development temperature squared and exposure times development temperature.

To obtain a meaningful regression model the exposure times from the composite design had to be converted to the actual exposure at the vesicular film surface. Using the characteristic curves, previously mentioned in the experimental section, the two log exposure values for the edge were averaged. This average log exposure value was then converted back to exposure to obtain the actual exposure at the vesicular film surface.

The final regression equations, for various frequencies, are shown in Figure 16. These equations provide a means of calculating an estimated MTF curve, for a vesicular sample, with exposure and development temperature being set at a certain value. However the regression equations in Figure 16 are only useful for the ranges of development temperature and exposure that were explored in the composite design.

Using these equations estimated MTF curves were drawn for two different treatment combinations. These estimated curves are compared to the actual MTF curves in Figures 17&18. There is a certain degree of error present between these two curves, and this can be attributed to several factors.

Several sources of experimental error were present in obtaining the film MTF curves. Focusing the microdensitometer to the most accurate level for the total 105 edges traces was hard, if not impossible, to achieve. Inaccurate focusing was not only caused by human error, but also

by the film sample not being perfectly flat while it was being scanned.

Any error that is present before the system MTF is calculated will be increased linearly with increasing frequency. This is due to the method of determining the system MTF and can be seen in Figure 19. This graph shows the average film MTF curve, for the central point of the composite design, with the maximum and minimum values for each frequency.

Due to the above factors there is error present in the regression model. However the error remained linear with frequency, as demonstrated in Figure 20 where R^2 (regression coefficient squared) is plotted as a function of frequency.

FIGURE 12.
FILM MTF CURVE FOR SAMPLE #2

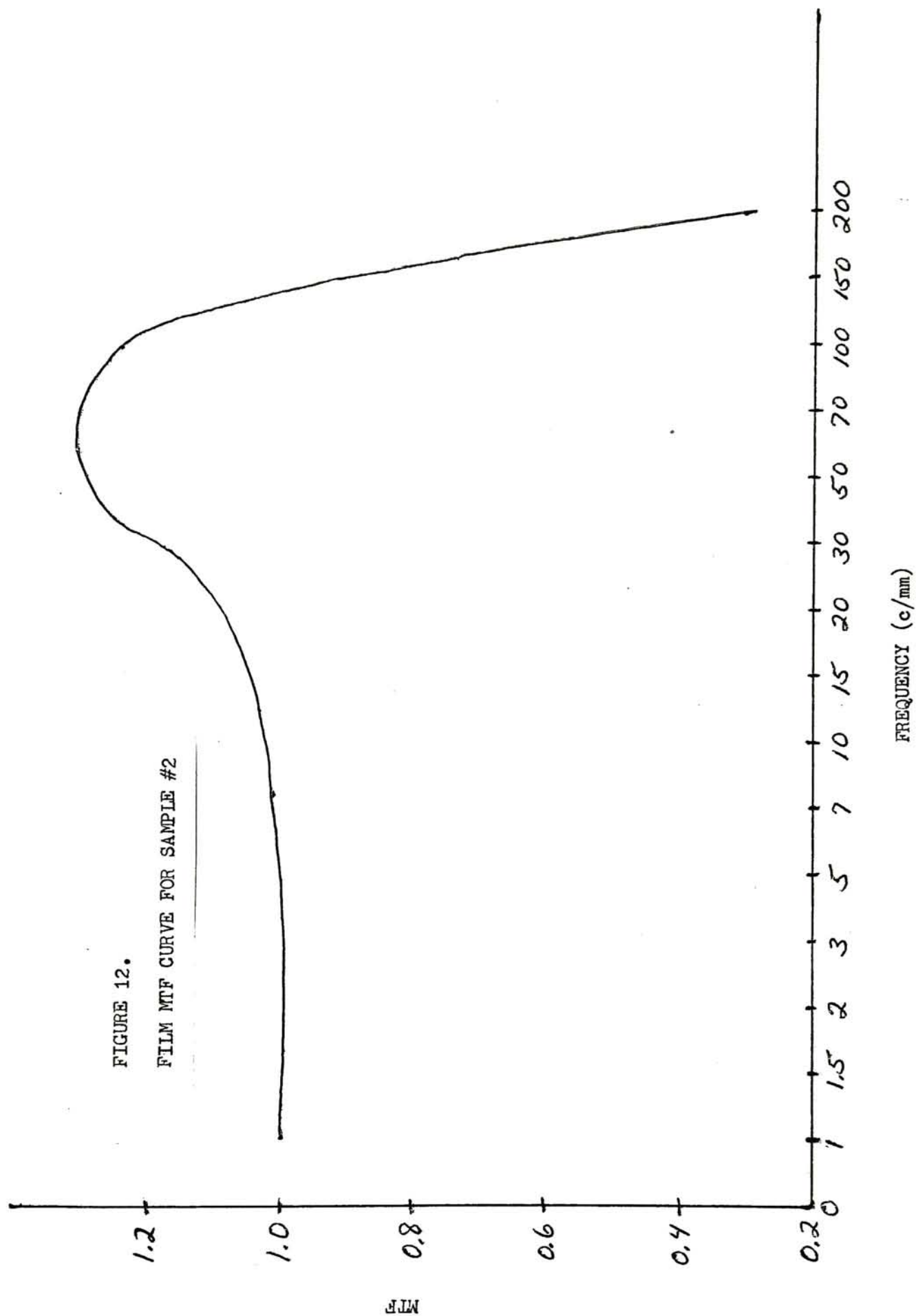


FIGURE 13.
DEVELOPMENT TEMPERATURE 240°F
DEVELOPMENT TIME 3 seconds

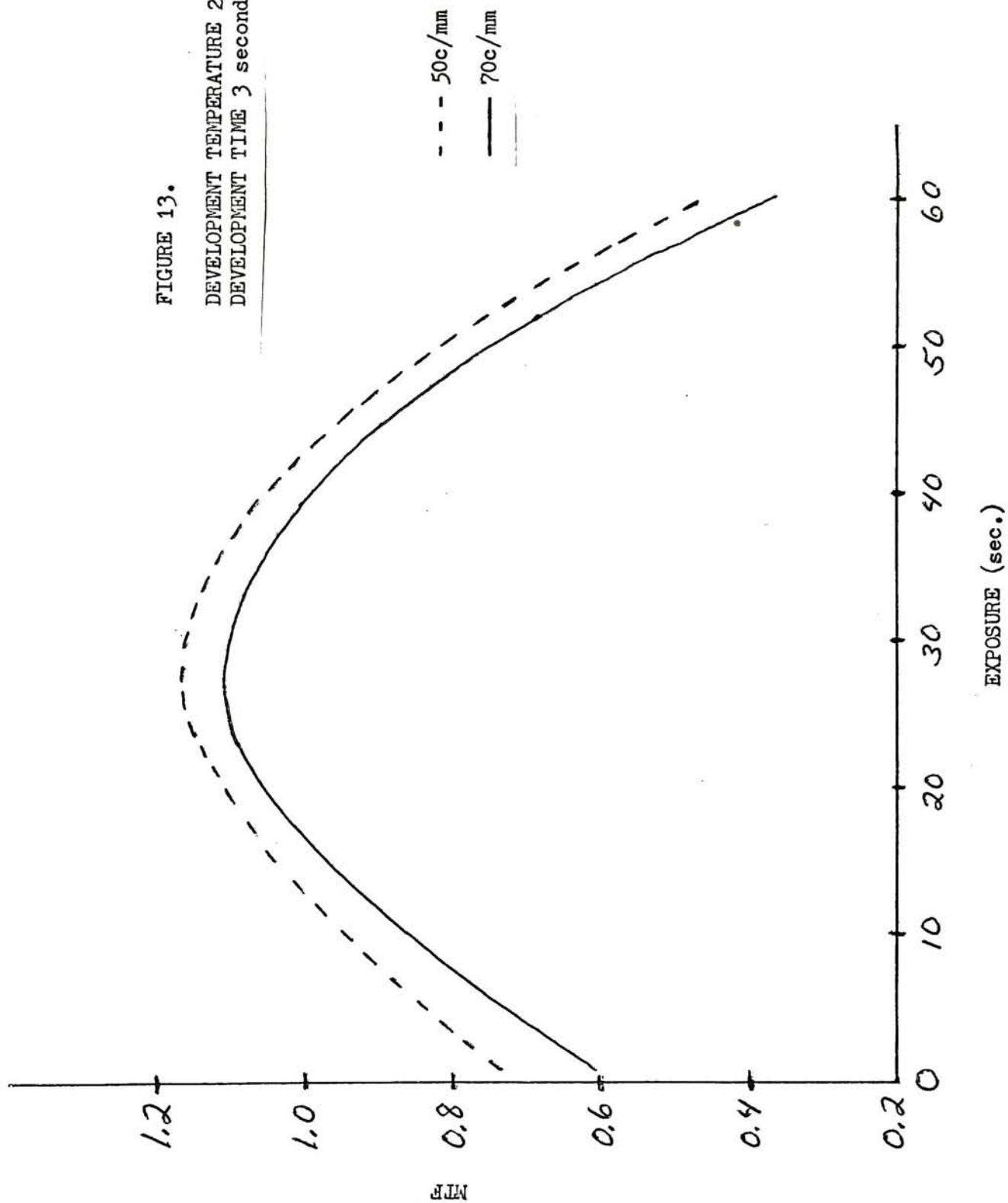
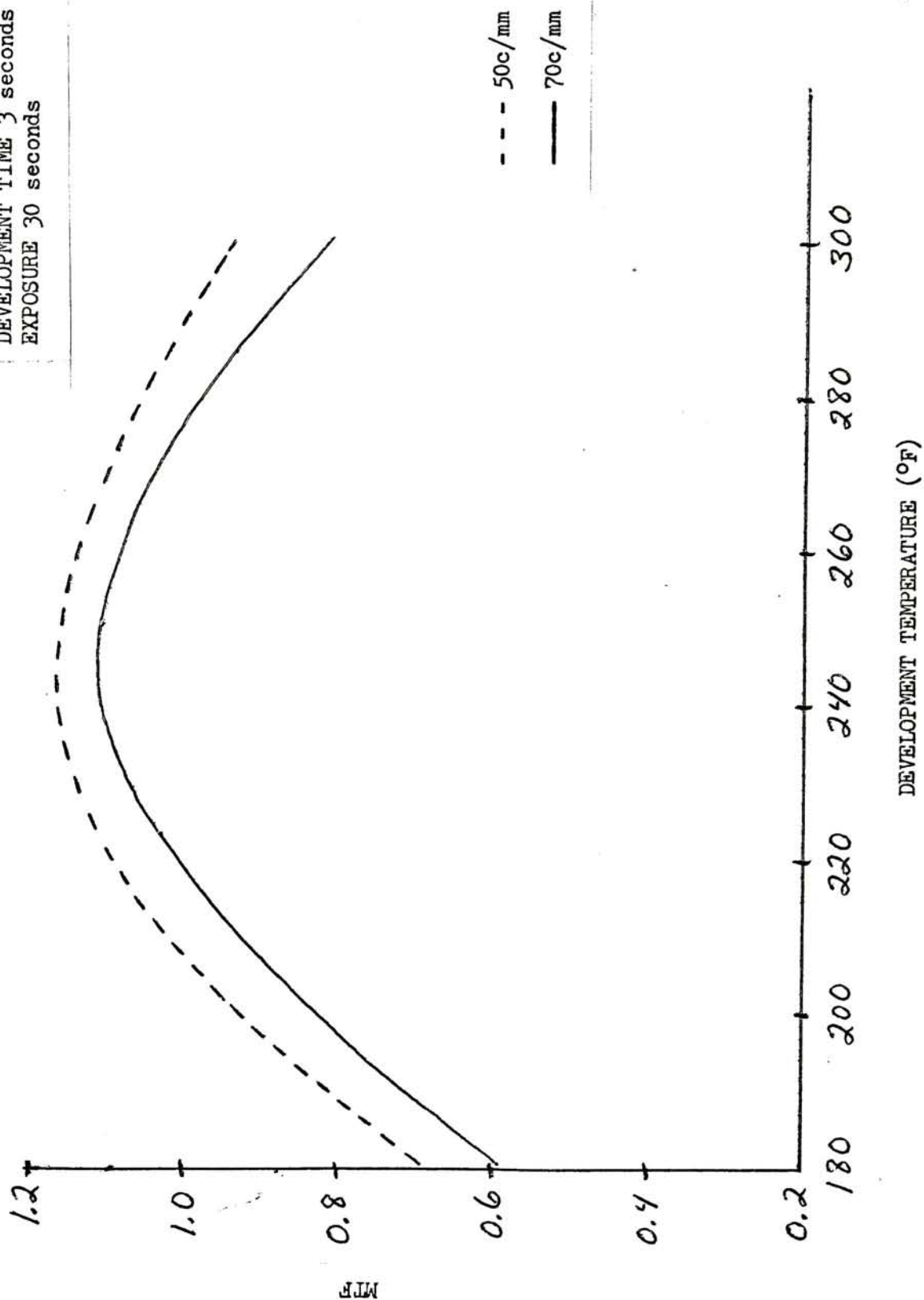


FIGURE 14.
DEVELOPMENT TIME 3 seconds
EXPOSURE 30 seconds



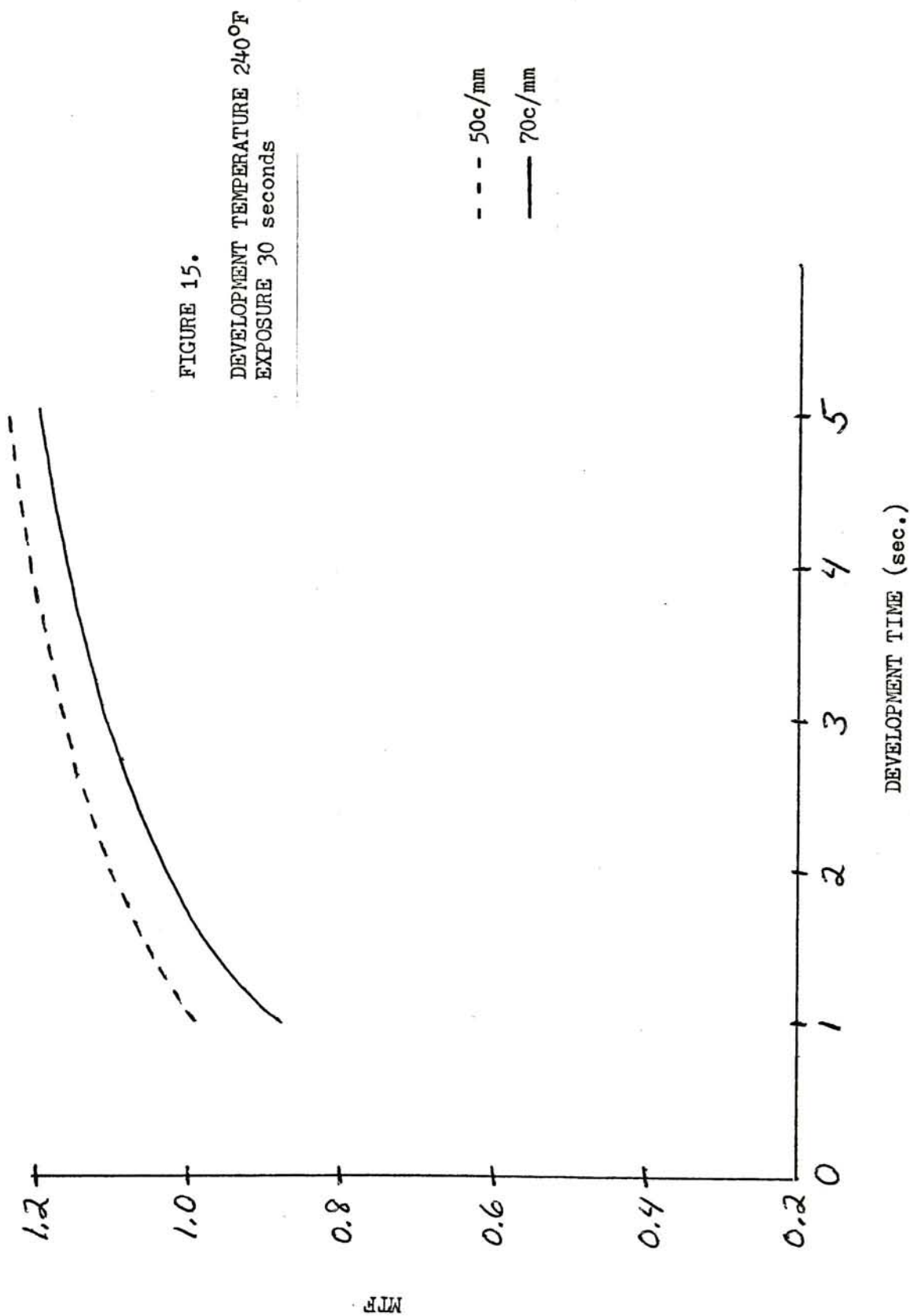


FIGURE 16.

REGRESSION EQUATIONS

Frequency (c/mm)

20	$Y = 0.3935 - 0.0042x^2 + 0.1303x - 0.0004xz + 0.0024z$
30	$Y = -0.0586 - 0.0048x^2 + 0.1930x - 0.0006xz - 0.0586z$
50	$Y = -4.7592 - 0.0099x^2 + 0.2934x - 0.0007xz + 0.0410z$ $-0.0001z^2$
70	$Y = -5.7002 - 0.0106x^2 + 0.3081x - 0.0008xz + 0.0477z$ $-0.0001z^2$
100	$Y = -5.4569 - 0.0095x^2 + 0.2597x - 0.0006xz - 0.0452z$ $- 0.0001z^2$
150	$Y = -2.4862 - 0.0060x^2 + 0.0003x - 0.0001z^2 + 0.0258z$ $- 0.0003xz$

Where: x = Exposure
 x^2 = (Exposure)²
 z = Development Temperature
 z^2 = (Development Temperature)²
 xz = Exposure x Development Temperature

REGRESSION COEFFICENTS

<u>Frequency (c/mm)</u>	<u>R value</u>
20	0.89
30	0.85
50	0.80
70	0.76
100	0.66
150	0.65

FIGURE 17. ACTUAL AND ESTIMATED MTF

DEVELOPMENT TEMPERATURE 276°F
DEVELOPMENT TIME 4.2 seconds
EXPOSURE 12 seconds

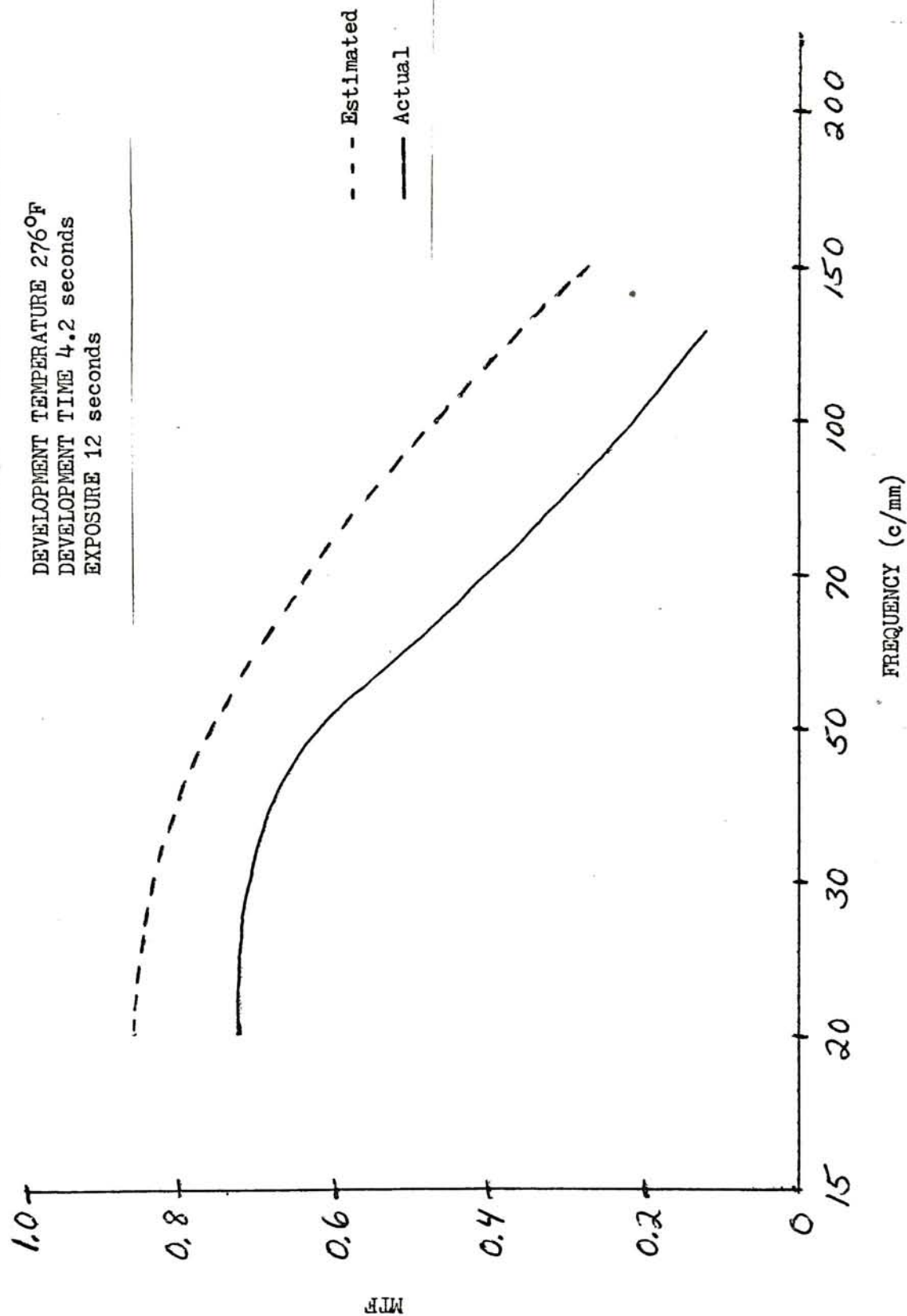


FIGURE 18. ACTUAL AND ESTIMATED MTF

DEVELOPMENT TEMPERATURE 240°F
DEVELOPMENT TIME 3 seconds
EXPOSURE 30 seconds

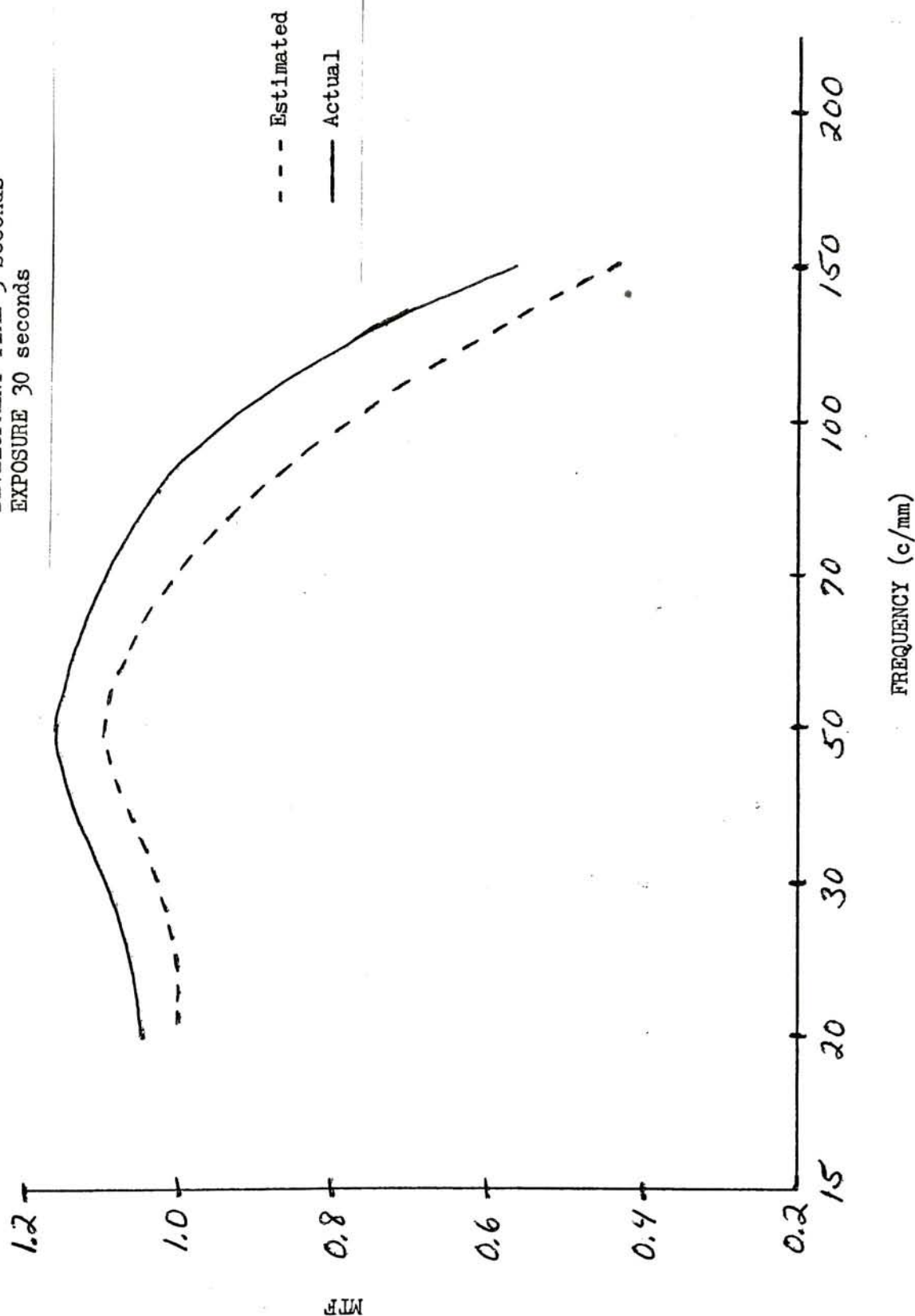


FIGURE 19.
MTF OF AVERAGE CENTER POINT
WITH MAX. AND MIN. VALUES OF
REPLICATES

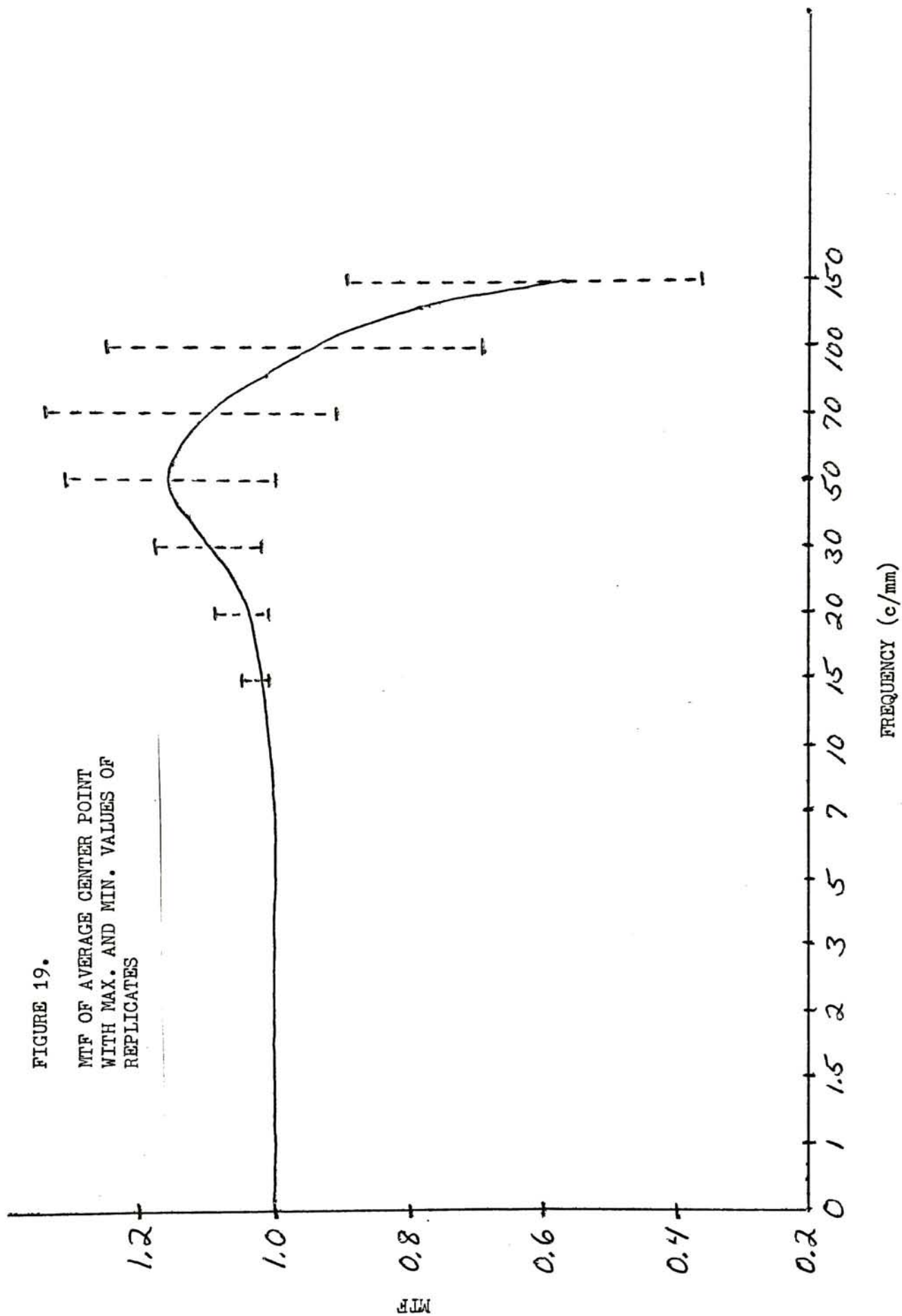
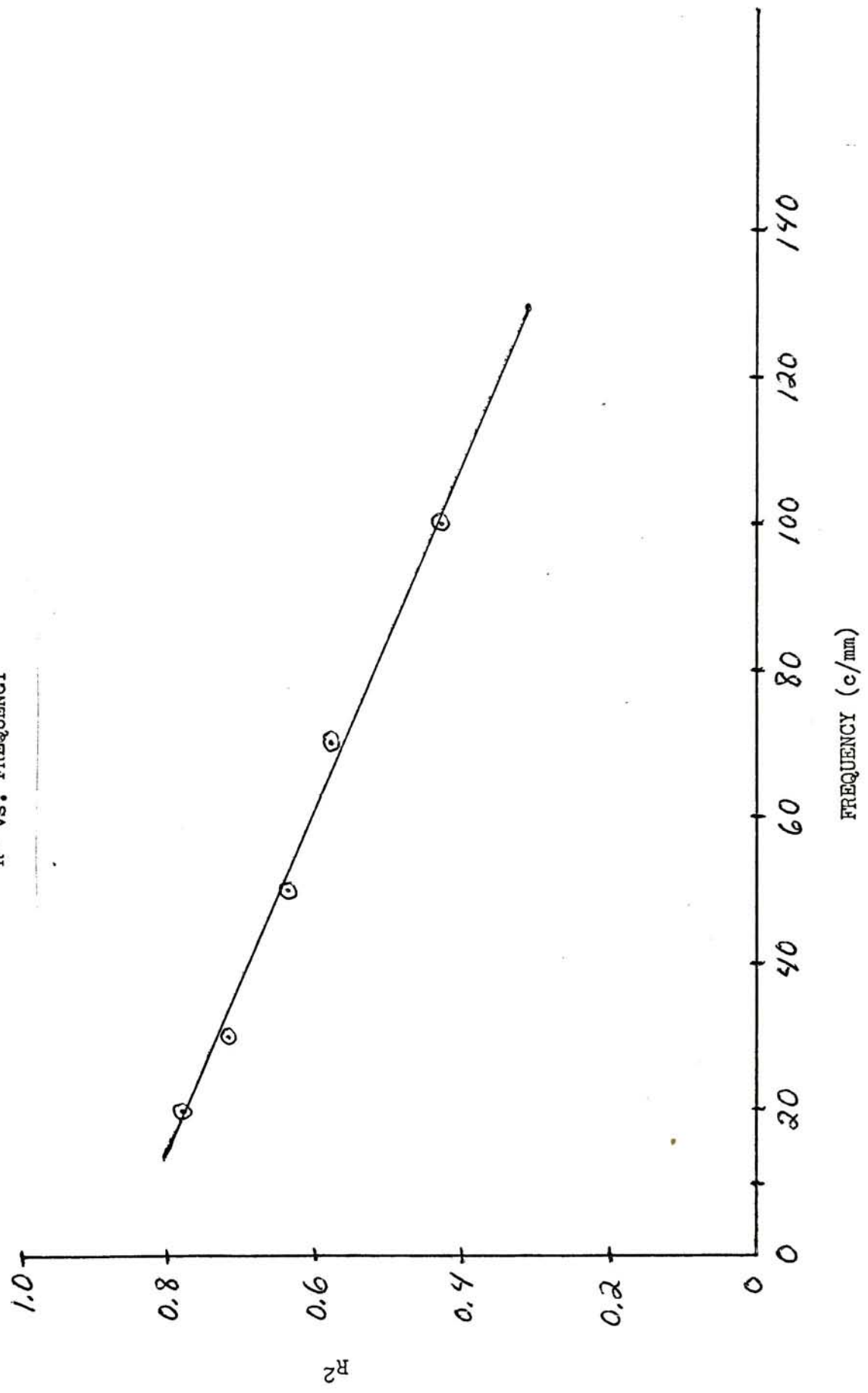


FIGURE 20.
 R^2 vs. FREQUENCY



CONCLUSION

The regression equations express the relationship between MTF and development temperature and exposure. It is clearly shown that development time is not a significant factor in calculating the film MTF curve.

These regression equations could be useful to the person who wants to know what the MTF curve of vesicular film is, for a certain situation, but either does not have the time or the equipment necessary to carry out an experiment. While there would be some error present in using these equations, they would still produce a worthwhile estimate of the film MTF.

Further investigation could be carried out in this area, with several modifications to the experimental work. By using a focus series on the microdensitometer some of the error may be taken out of the edge traces. Also to improve the edges produced a low contrast NBS edge should be used in the exposing of the vesicular samples. This would be beneficial due to the high gamma values of vesicular film. Finally, by increasing the size of the experimental design, so that more points are explored within the given ranges of the variable parameters, it may be possible to obtain a better fit for the regression model.

ACKNOWLEDGMENTS

The authors wish to thank Xidex Corporation, for providing vesicular film, and Mr. Richard Swing, for donating an NBS edge.

The authors are very grateful to their thesis advisor, Dr. Ed Granger, who was of great assistance in the completion of this study.

Also the authors wish to express their thanks to Mr. John Blakney for his help and guidance in running the computer programs.

APPENDIX 1.

```
C PROGRAM EDGEFT
C VERSION 0.0 APRIL 1, 1977
C
C WRITTEN BY DR. E. M. GRANGER
C F.T. METHOD AS DESCRIBED BY STRAW
C MODIFIED FOR RIT SIGMA 9 BY JOHN BLAKNEY
C
C
C INPUT IS THROUGH F:20
C OUTPUT IS THROUGH F:108
C
C
C DIMENSION OF F, T1, T2 MUST AGREE WITH NF BELOW
C E IS DIMENSIONED AT LEAST AS LARGE AS THE GREATEST NUMBER OF SAMPLES
  DIMENSION F(15),T1(5,15),T2(5,15),E(75),AA(4)
  DIMENSION TT1(15),TT2(15)
C DELX IS THE SAMPLE SPACING IN MM
  REAL DELX/0.00125/
  REAL PI/3.1415926/
C NF IS THE NUMBER OF FREQUENCIES TO BE ANALYZED
  INTEGER NF/15/
  DATA F/1,1.5,2,3,5,7,10,15,20,30,50,70,100,150,200/
C
C
C
999  DO 10 I=1,5
      DO 10 J=1,NF
        T1(I,J)=0.
10    T2(I,J)=0.
      DO 11 J=1,NF
        TT1(J)=0.
11    TT2(J)=0.
      WRITE(108,902)
902  FORMAT('1')
      DO 1 I=1,5
C DO THIS LOOP ONCE FOR EACH OF THE FIVE TRACES IN A SET
C FIRST READ ID LINE
      READ(20,900) AA(1),AA(2),AA(3),AA(4)
900  FORMAT(A4,A3,I2,A2)
      IF(AA(3).EQ.0),GO TO 1000
      WRITE(108,901) AA(3),AA(4)
901  FORMAT('//10X,'DATA FOR TRACE ',I2,A2,/)
C NOW FIND OUT HOW MANY POINTS ARE IN THE TRACE
      READ(20,903) N
903  FORMAT(I2)
C N IS THE NUMBER OF POINTS TO READ
      WRITE(108,904) N
904  FORMAT(' ','# POINTS = ',I2,/)
C NOW READ THE DATA POINTS
      READ(20,905) E(I5) I5=1,N
905  FORMAT(F3.2)
      M=N
      WRITE(108,907)
```

*

APPENDIX 1.

```

WRITE(108,907)
907  FORMAT(' DENSITIES OF TRACE')
WRITE(108,906) E(I5),I5=1,N
906  FORMAT(26(1X,F4.2))
908  FORMAT(3/)
C CONVERT FROM DENSITY TO TRANSMITTANCE
DO 2 J=1,M
2    E(J)=10.**(-E(J))
C THIS SECTION NORMALIZES TRANSMITTANCES TO A RANGE OF 0 TO 1
EMAX=E(1)
EMIN=E(1)
IF (E(M).GT.EMAX) EMAX=E(M)
IF (E(M).LT.EMIN) EMIN=E(M)
EDEL=EMAX-EMIN
DO 3 J=1,M
3    E(J)=(E(J)-EMIN)/EDEL
C THIS SECTION IS THE FOURIER TRANSFORM WHICH SUMS
C THE COEFFICIENTS FOR FIVE SAMPLES
DO 4 J=1,NF
A=PI*DELX*F(J)
NS=(M+1)/2
DO 5 K=1,M
T1(I,J)=T1(I,J)+E(K)*SIN(2*A*(K-NS))
5    T2(I,J)=T2(I,J)+E(K)*COS(2*A*(K-NS))
T1(I,J)=T1(I,J)*A*2+COS(M*A)*A/SIN(A)
4    T2(I,J)=T2(I,J)*A*2-SIN(M*A)*A/SIN(A)
WRITE(108,911)F(J),T1(I,J),T2(I,J),
1  SQRT(T1(I,J)*T1(I,J)+T2(I,J)*T2(I,J)),J=1,NF
911  FORMAT(//,X,'FREQ      T1      T2      MTF',/,
1    (X,F5.1,F8.3,X,F8.3,F9.5))
1    CONTINUE
C ALL 5 CURVES HAVE NOW BEEN PROCESSED
C COMPUTE THE AVERAGE MTF
WRITE(108,912) AA(3)
912  FORMAT('1',///10X,'SUMMARY FOR DATA SET ',I3)
DO 6 I=1,5
DO 6 J=1,NF
TT1(J)=TT1(J)+T1(I,J)/5.
6    TT2(J)=TT2(J)+T2(I,J)/5.
WRITE(108,913) F(J),TT1(J),TT2(J),J=1,NF
913  FORMAT(//,X,'FREQ      T1      T2',/,(X,F5.1,F9.3,F9.3))
DO 7 J=1,NF
7    TT1(J)=SQRT(TT1(J)*TT1(J)+TT2(J)*TT2(J))
C NOW OUTPUT THE MTF'S
WRITE(108,902)
909  FORMAT('0',15X,'MTF FOR SET ',I2,/,3X,
1    3' FREQ      MTF      ',/)
WRITE(108,909) AA(3)
910  FORMAT(3(3X,F5.1,2X,F8.6))
WRITE(108,910) F(I),TT1(I),F(I+5),TT1(I+5),
1  F(I+10),TT1(I+10),I=1,5
C NOW RETURN TO THE BEGINNING AND DO THE NEXT SET OF CURVES
GO TO 999
1000 CALL EXIT
END

```

*

REFERENCES

1. W. Thomas Jr., Editor, S.P.S.E. Handbook , John Wiley and Sons Inc., New York (1973), p. 372-373, 510, 870, 1191-1193
2. J. Kosar, Light-Sensitive Materials , John Wiley and Sons Inc., New York (1965), p. 179, 276-280
3. N.T. Notley, Photogr. Sci. Eng. , Vol. 2, Number 1 (1967) p. 2-7
4. R.T. Nieset, J. Photo. Sci. , Vol. 10, Number 3 (May/June 1962) p. 188-195
5. N.R. Bacon and R.B. Lindemeyer, J. S.M.P.T.E. , Vol. 73* (March 1964) p. 213-215
6. Anon., British J. Photo. , Vol. 110 (Nov. 1963), p. 976-981
7. E.J. Barlow and W.E. Langlois, I.B.M. J. of Res. and Dev. , Vol. 6 (July 1962) p. 329-337
8. M.E. Rabedeau, Photogr. Sci. Eng. , Vol. 9, Number 1 (Jan./Feb. 1965) p. 58-62
9. N.T. Notley, Photogr. Sci. Eng. , Vol. 10, Number 1 (Jan./Feb. 1966) p. 3-7
10. R.T. Nieset, Litho-Printer , Vol. 7 (May 1964), p. 29-30
11. A.T. Ram and E.W. Potter, Photogr. Sci. Eng. , Vol. 14, Number 4 (July/August 1970), p. 283-288
12. J. Norcross, S.P.S.E. Symp. Unconv. Photo. Sys. , 20-23 (Oct. 1971) p. 104-105
13. S. Chaikin, B. Nam, H. Meyers and P. Voisin, S.P.S.E. Symp. Unconv. Photo. Sys. , 20-23 (Oct. 1971), p. 105-106
14. V. Wagner, S.P.S.E. Symp. Elec. Image Sys. , (April 12-15, 1970), p. 147-155
15. D. Galburt, R.A. Jones and J.W. Bossung, Photogr. Sci. Eng. , Vol. 13, Number 4 (July/August 1969), p. 205-209
16. C.H. Barrow, Photogram. Eng. , Vol. 32, (Jan. 1966), p. 113-120
17. H.B. Hammill and Dr. T.M. Holladay, J. S.P.I.E. , Vol. 8, Number 6 (1970), p. 223-228

18. R.A. Jones, Photogr. Sci. Eng. , Vol. 9, Number 6, (Nov./Dec. 1965),
p. 355-359
19. R.A. Jones, Photogr. Sci. Eng. , Vol. 11, Number 2 (March/April 1967),
p. 102-106
20. R.A. Jones and J.F. Coughlin, Applied Optics , Vol. 5, Number 9 (Sept. 1966),
p. 1411-1414
21. K. Straw, The MTF and Other Characteristics of Kodak 4-X Reversal Film , Master's Thesis, University of Rochester, Optics Institute, 1973